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Title: Simple grab sampling methods for the measurement of WL(Rn) and WL(Tn) concentrations

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Simple Grab Sampling Methods for the Measurement of WL(Rn) and WL(Tn) Concentrations, Alan Justus, RP-SVS, June 5, 2018, LA-UR-18-xxxxx

WL(Rn) Alone

If one is air sampling for short-lived radon (^{222}Rn) progeny only, then it is the so-called working level concentration (WL) that is normally determined. Often, a so-called short-term grab air sample is utilized followed by gross α counting techniques. Care on the part of health physics personnel is required here, as is an uninterrupted work time. With the aid of a stopwatch, the sample must be taken for a precise time period (i.e., in this case, a 5 minute sample) and the gross α activity must also be counted for precisely 5 minutes after a certain precise waiting period (i.e., either a 4 minute wait per a Borak-modified Rolle method, or a 40 minute waiting period per a Borak-generalized Kusnetz method). For this sampling method, Table 1 below lists the conversion factors relating the gross α activity in dpm to the average working level concentration in WL for ten different values of the so-called average age of the air, normalized to 1 lpm of sample flow rate. The average age of the air, i.e., the time that the radon progeny have had toward growth to equilibrium with the parent radon, corresponds to the mean life of the sampled air, which in turn is related to the effective ventilation exchange rate. If the age of the air can be readily estimated, then either the 3rd or 4th columns of Table 1 below may be utilized to convert the measured gross α dpm to the WL. If time is limited, then the 3rd column may be utilized; however, the result is slightly more sensitive to the choice of the age of the air. If the age of air is quite uncertain, then both the 3rd and 4th columns may be utilized together (from two separate counts of the same sample) to determine both the WL and the average age of the air.

Table 1. Conversion factors (as dpm per WL·lpm) for the two sampling regimes versus the average age of air (min) and, equivalently, the effective ventilation exchange rate (h^{-1}).

		Modified Rolle	Generalized Kusnetz
		T_S = 5 min	T_S = 5 min
		T_W = 4 min	T_W = 40 min
		T_C = 5 min	T_C = 5 min
Average Age of Air (min)	Effective Ventilation Exchange Rate (h^{-1})		
5	12	1435	603.8
10	6	1251	666.1
20	3	1111	723.9
30	2	1094	743.0
40	1.5	1110	749.0
50	1.2	1134	750.2
60	1	1157	749.8
120	0.5	1240	743.4
180	0.33	1264	740.8
240	0.25	1270	740.1
	median(±span%):	1265(±13.5%)	677.0(±10.8%)

Note that T_S is the sampling time, T_W is the waiting time, and T_C is the count time.

Example 1. A 5-minute air sample is taken at a sample flow rate of 50 lpm utilizing an open-faced filter holder. A gross α counter, with a counting efficiency of 0.25 and essentially no background, is used to count the filter post sampling. A 5-minute count initiated after a 4-minute delay yields 71 counts. A second 5-minute count initiated after a 40-minute delay yields 46 counts. What was the WL(Rn) concentration sampled? The calculated gross α activities are 56.8 and 36.8 dpm during the first and second counting intervals, respectively. To a first approximation, without knowledge of the average age of the air, the WL determined from the first count is:

$$\frac{56.8\ dpm}{\left(1265\frac{dpm}{WL}\cdot lpm\right)\cdot 50lpm} = 0.9\ mWL$$

and that from the second count is:

$$\frac{36.8\ dpm}{\left(677.0\frac{dpm}{WL}\cdot lpm\right)\cdot 50lpm} = 1.1\ mWL$$

The average is 1 mWL. However, with the added knowledge that the effective air exchange rate is about 1 h^{-1}, conversion factors of 1157 and 749.8 both yield 0.98 mWL. Hence, the measured WL(Rn) is about 1 mWL.

Both WL(Rn) and WL(Tn)

If one is air sampling for short-lived radon (^{222}Rn) progeny and thoron (^{220}Rn) progeny, then both the WL(Rn) and WL(Tn) are normally determined. Again, a short-term grab air sample is utilized. However, te sampling time is typically extended to 10 minutes, which is then followed by either gross α or α spectroscopic counting techniques. Care on the part of health physics personnel is still required here. With the aid of a stopwatch, the sample must be taken for a precise time period (i.e., in this case a 10 minute sample).

The gross α activity must be counted twice: (1) for precisely 10 minutes after a certain waiting period (i.e., a 40 minute waiting period per a Borak-generalized Kusnetz method), and (2) for precisely 60 minutes after a 300 minute (i.e., 5 hour) waiting period (per a generalized two-count method). For these sampling intervals, Table 2 below lists the conversion factors relating the gross α activity in dpm to the average working level concentration (in WL(Rn) or WL(Tn), as appropriate) for ten different values of the average age of the air, normalized to 1 lpm of sample flow rate.

Note that the average age of the air in this case corresponds to the time that the radon-222 progeny have had toward growth to secular equilibrium with the parent radon, and the time that the radon-220 progeny have had toward growth to transient equilibrium. The average age of air still corresponds to the mean life of the sampled air, which in turn is the reciprocal to the effective ventilation exchange rate.

Table 2. Conversion factors (as dpm per WL·lpm) for the Two-Count Method versus the average age of air (in min).

Average Age of Air (min)	Generalized Kusnetz T_S = 10 min T_W = 40 min T_C = 10 min		2nd-Count T_S = 10 min T_W = 300 min (i.e., 5 hour) T_C = 60 min (i.e., 1 hour)	
	WL(Rn)	WL(Tn)	WL(Rn)	WL(Tn)
5	1159	76.93	2.214	134.5
10	1273	77.41	2.341	134.5
20	1372	78.29	2.369	134.4
30	1400	79.08	2.297	134.3
40	1404	79.79	2.212	134.2
50	1402	80.44	2.135	134.2
60	1397	81.01	2.071	134.1
120	1373	83.46	1.874	133.9
180	1366	84.77	1.822	133.8
240	1364	85.47	1.809	133.7
median:	1282(±9.6%)	81.2(±5.3%)	2.089(±13.4%)	134.1(±0.3%)

Example 2. A 10-minute air sample is taken at a sample flow rate of 50 lpm utilizing an open-faced filter holder. A gross α counter, with a counting efficiency of 0.25 and essentially no background, is used to count the filter post sampling. A 10-minute 1st-count initiated after a 40-minute delay yields 174 counts. A 60-minute 2nd-count initiated after a 5-hour delay yields 20 counts. What were the WL(Rn) and WL(Tn) concentrations sampled? The calculated gross α activities are 69.6 and 1.33 dpm during the first and second counting intervals, respectively. To a first approximation, without knowledge of the average age of the air and neglecting the extremely small Rn-progeny cross-talks, the WL determined from the first count is:

$$\frac{69.6\ dpm}{\left(1282\,\frac{dpm}{WL(Rn)}\cdot lpm\right)\cdot 50\ lpm} = 1.1\ mWL(Rn)$$

and that from the second count is:

$$\frac{1.33\ dpm}{\left(134.1\,\frac{dpm}{WL(Tn)}\cdot lpm\right)\cdot 50 lpm} = 0.2\ mWL(Tn)$$

However, with the added knowledge that the effective air exchange rate is about 1 h^{-1}, a conversion factor of 1397 yields 0.98 mWL(Rn). Hence, the measured concentrations are about 1 mWL(Rn) and 0.2 mWL(Tn). The crosstalk of Tn into the first count is estimated to be only 0.8 dpm (i.e., 81·50·0.0002), which is negligible. The crosstalk of Rn into the second count is estimated to be only 0.1 dpm (i.e., 2.07·50·0.0011), which is also negligible.

If α spectroscopic instrumentation is available, then the individual 6, 7.69, and 8.78 MeV peak activities can be counted in lieu of the gross α activity. Counting is only necessary in the 1st-Count period alone. Counting must still be for precisely 10 minutes after a 40 minute waiting period, however, per the Borak-generalized Kusnetz method. For this sampling interval, Table 3 below lists the conversion factors relating the α spectroscopic activity in dpm to the average working level concentration (in WL(Rn) or WL(Tn), as appropriate) for ten different values of the average age of the air, normalized once again to 1 lpm of sample flow rate.

Table 3. Conversion factors (as dpm per WL·lpm) for the Alpha Spectroscopic technique versus the average age of air (min).

	Alpha Spectroscopic Technique at 1st-Count	
	T_S = 10 min	
	T_W = 40 min	
	T_C = 10 min	
Average Age of Air (min)	WL(Rn) (based on 7.69 MeV α plus corr. 6 MeV α)	WL(Tn) (based on 8.78 MeV α activity only)
5	1159	120.1
10	1273	120.8
20	1372	122.2
30	1400	123.4
40	1404	124.6
50	1402	125.6
60	1397	126.5
120	1373	130.3
180	1366	132.3
240	1364	133.4
median:	1282(±9.6%)	126.8(±5.2%)

Example 3. A 10-minute air sample is taken at a sample flow rate of 50 lpm utilizing an open-faced filter holder. An α spectrometer, with a counting efficiency of 0.25 and essentially no background, is used to count the filter post sampling. A 10-minute α spectroscopic count initiated after a 40-minute delay yields integral counts of 20, 154, and 3 counts under the 6, 7.69, and 8.78 MeV peaks, respectively. What were the WL(Rn) and WL(Tn) concentrations sampled? The calculated peak activity at 8.78 MeV is 1.2 dpm. To the first approximation, without knowledge of the average age of the air, the WL(Tn) determined from the 8.78 MeV peak count is:

$$\frac{1.2\,dpm}{\left(126.8\frac{dpm}{WL(Tn)}\cdot lpm\right)\cdot 50lpm} = 0.2\,mWL(Tn)$$

The sum of the 6 and 7.69 MeV peaks is 174 counts. The calculated summed activity is therefore 69.6 dpm. However, 56.1% of the 1.2 dpm activity observed at 8.78 MeV should be subtracted from this sum, yielding a corrected sum of 68.9 dpm. Hence, to the first approximation (without knowledge of the average age of the air):

$$\frac{68.9\ dpm}{\left(1282\frac{dpm}{WL(Rn)}\cdot lpm\right)\cdot 50lpm}=1.1\ mWL(Rn)$$

However, with the added knowledge that the effective air exchange rate is about 1 h^{-1}, a conversion factor of 1397 yields 0.99 mWL(Rn). Hence, the measured concentrations were about 1 mWL(Rn) and 0.2 mWL(Tn).

Bibliography

Borak TB. A method for prompt determination of working level using a single measurement of gross alpha activity. Rad. Prot. Dos. 19(2):97-102; 1987.

Kusnetz HL. Radon daughters in mine atmospheres, a field method for determining concentrations. Am. Ind. Hyg. Assoc. Quart. 17(1):85-88; 1956.

Rolle R. Rapid working level monitoring. Health Phys. 22:233-238; 1972.

Yang FC, Tang CY. A general formula for the measurement of concentrations of radon and thoron daughters in air. Health Phys. 34: 501-503; 1978.